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TAKE A WALK ON THE DARKSIDE

status and challenges of the Darkside-20k experiment

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	liquid Ar	liquid Xe
Z (A)	18 (40)	54 (131)
temperature	87 K (close to nitrogen)	166 K
density	1.4 g/cm^3	3.1 g/cm^3
ionisation yield	42 e$^-$/keV	64 e$^-$/keV
scintillation yield	40 ɣ/keV	46 ɣ/keV
scintillation wavelength	128 nm	178 nm
radio-purity	^{39}Ar contamination, can be reduced	intrinsically pure
pulse-shape discrimination	yes (singlet ~7 ns, triplet ~1600 ns)	very limited (singlet ~2 ns; triplet ~27 ns)
sensitivity	better for m_{WIMP} > 100 GeV spin-independent only	also to low masses and spin-dependent

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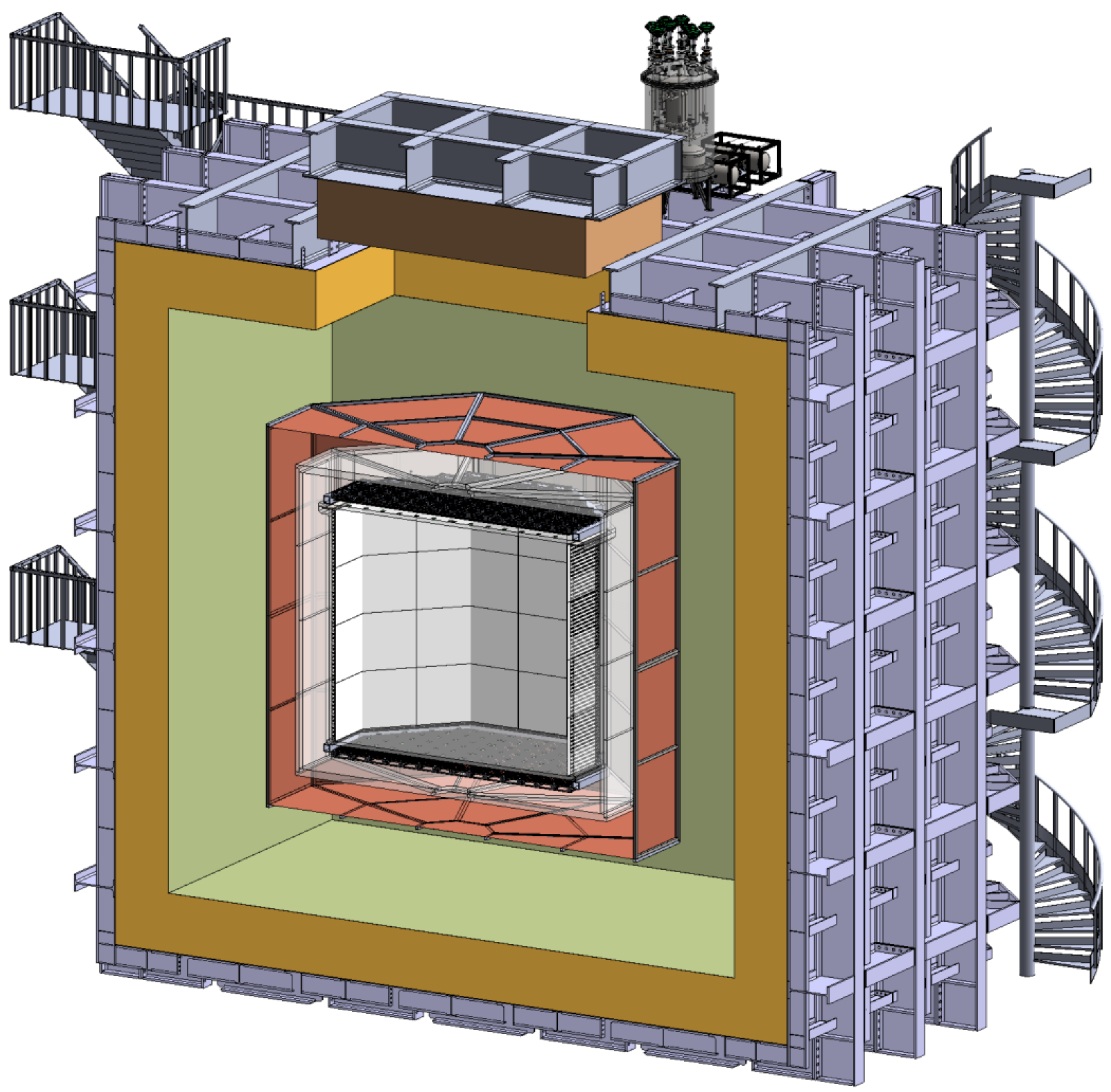

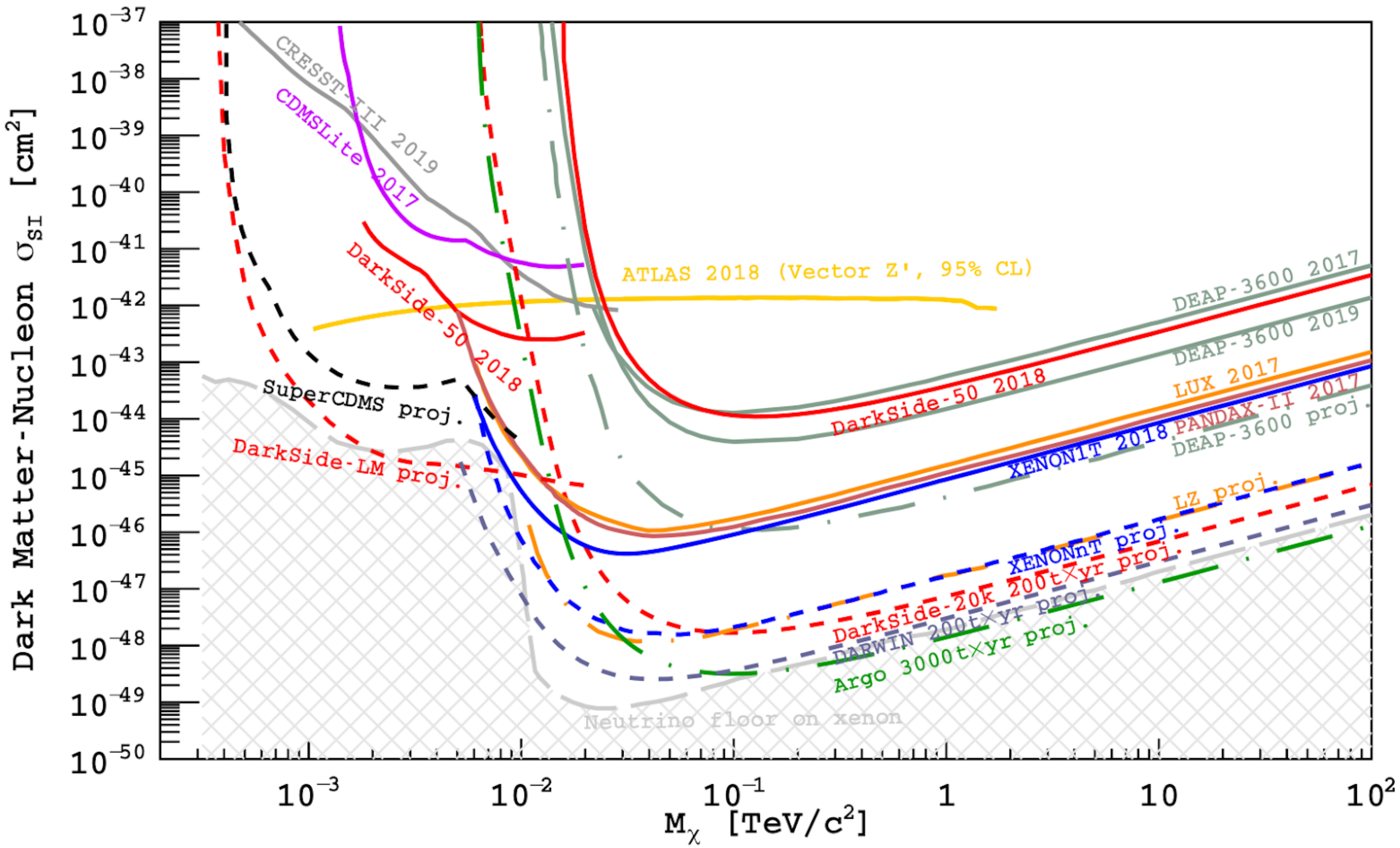

Darkside-20k

- n veto: **atmospheric** Ar, acrylic+Gd
- TPC: **underground** Ar, acrylic
- 3.5 m **drift** & many channels: challenging TDAQ

@100 GeV:
- DS-20k: 2×10^{-48} cm^2
- Argo (300 t): 3×10^{-49} cm^2

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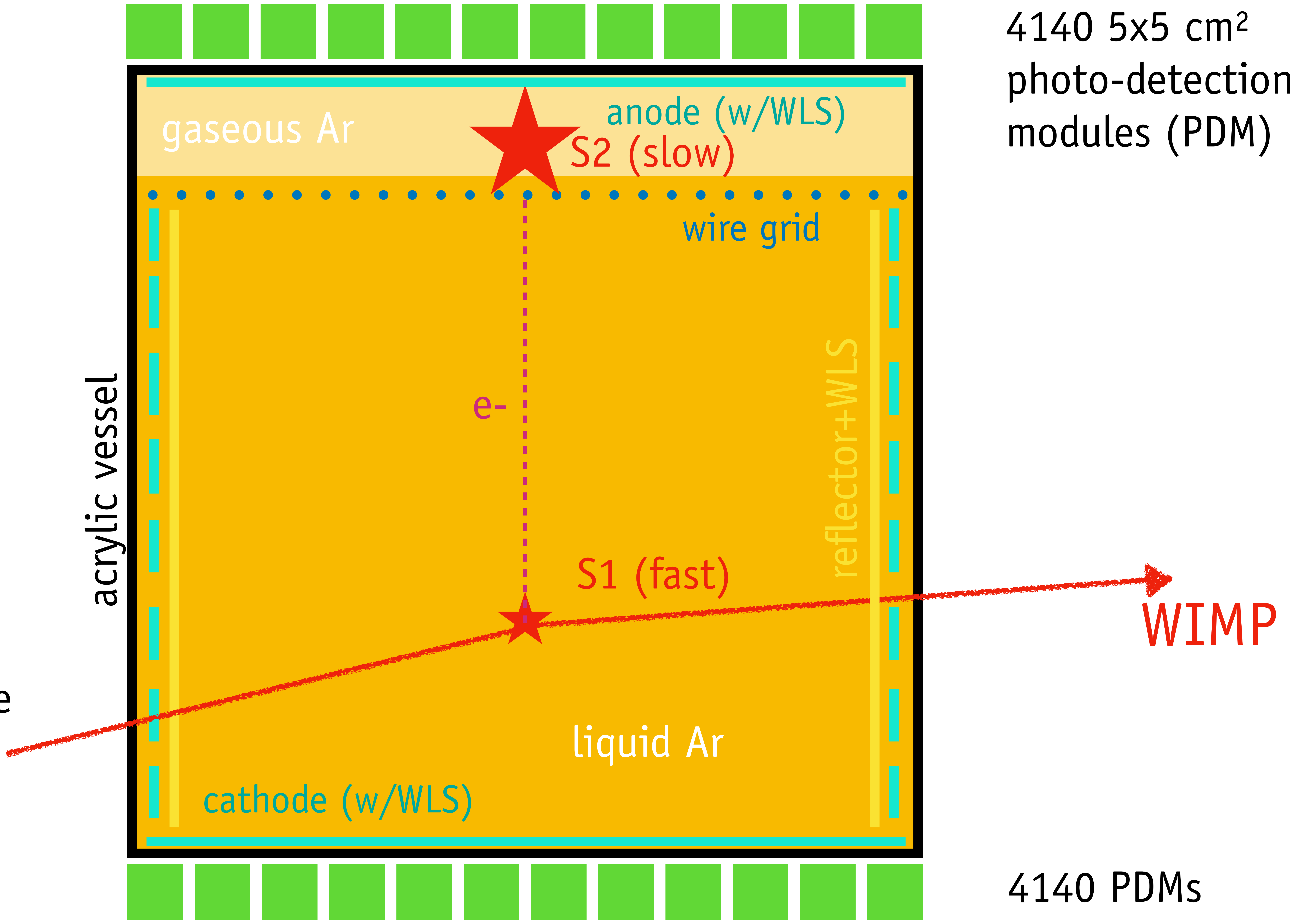
key ideas:

- TPC with 20 tons of fiducial volume of ultrapure argon (URANIA+ARIA)
- embedded in veto detector immersed in atmospheric argon
- SiPMs to replace PMTs used by previous experiment version (DS-50)



4140 5x5 cm^2 photo-detection modules (PDM)

4140 PDMs

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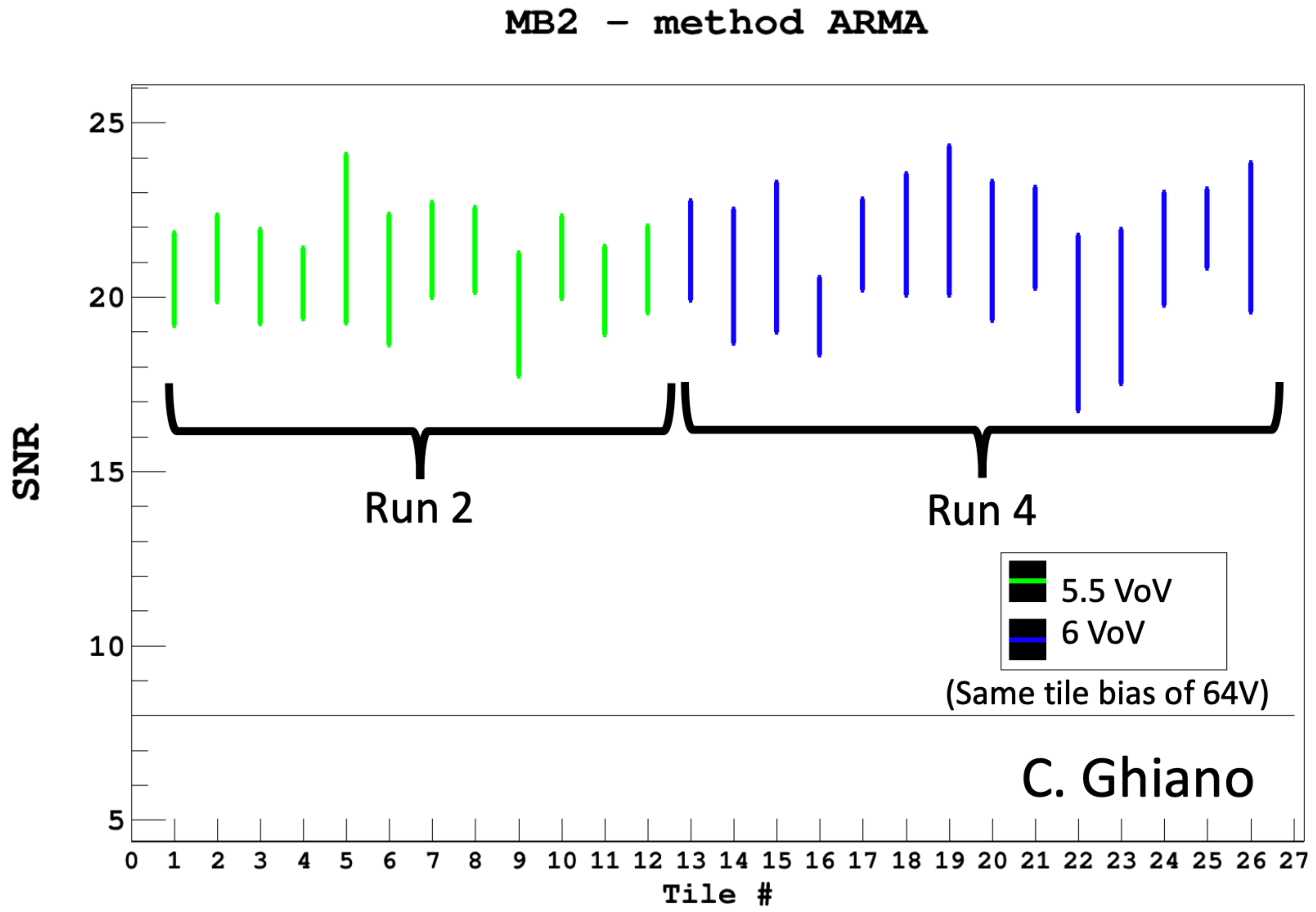
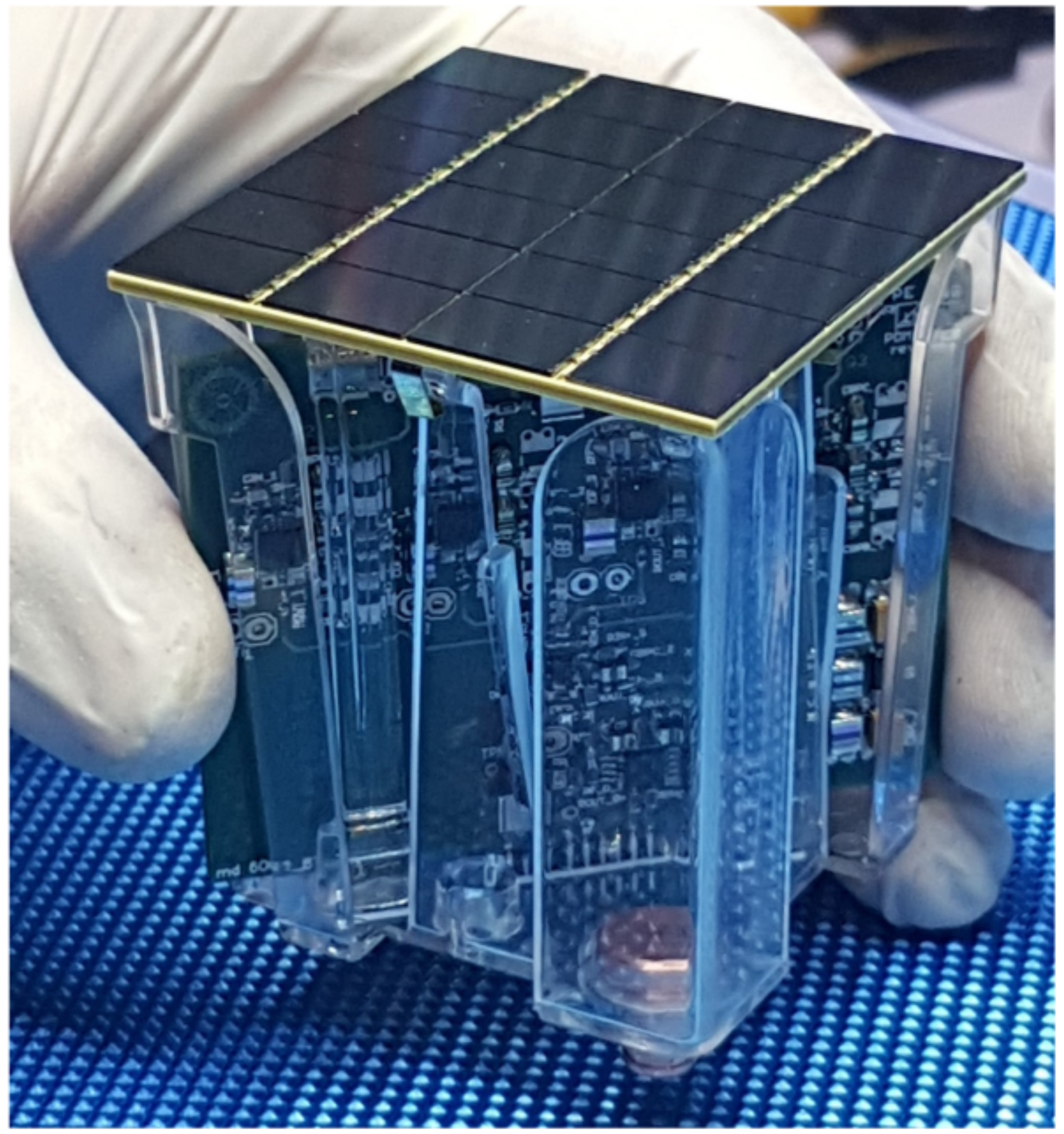
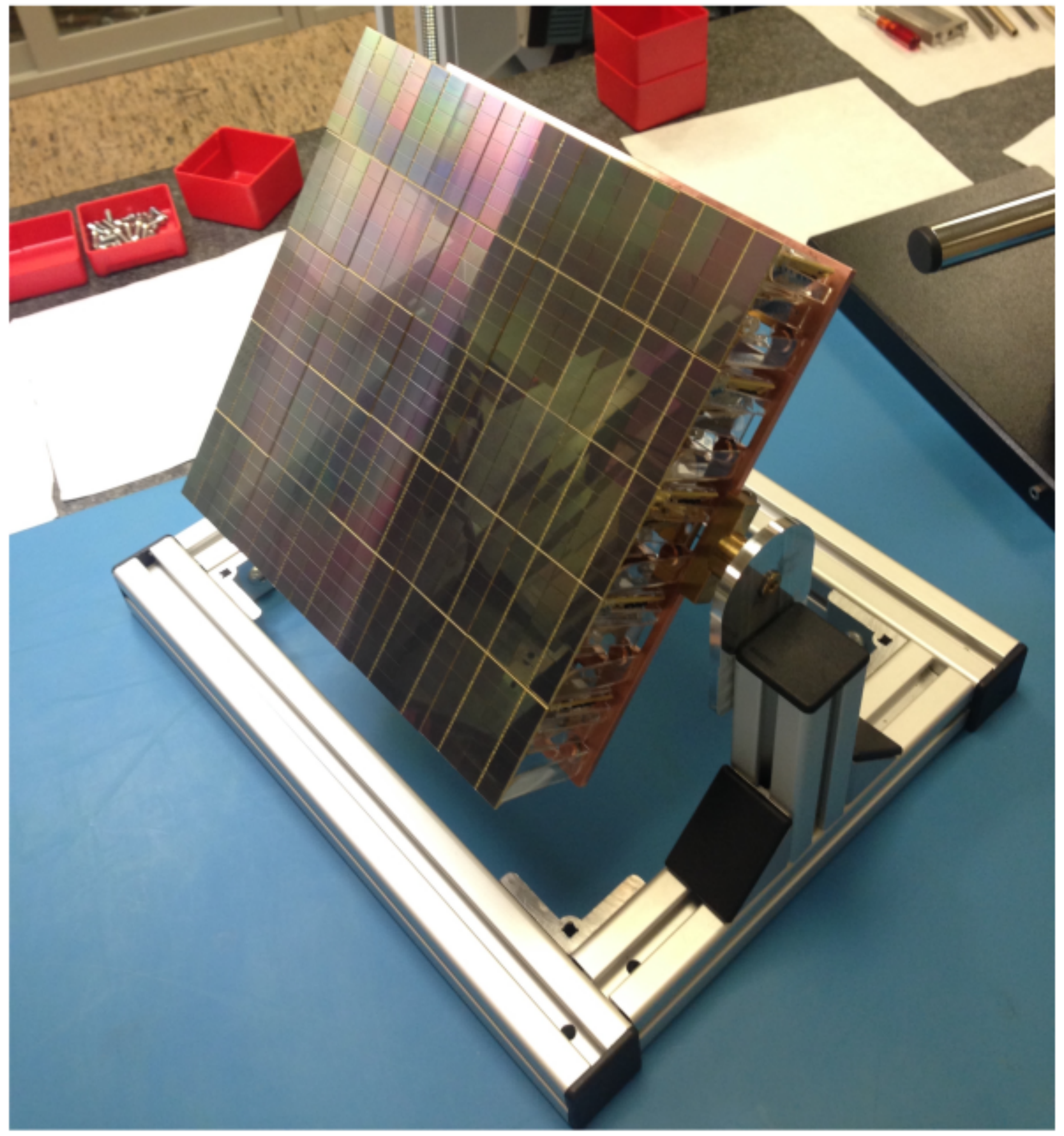
Luminous

- replace PMTs with SiPMs
  - efficiency ~ 50%, resolution, SNR > 8, cost, radio-purity
  - 8x12 mm FBK LF NUV-HD
- photo-detection module (38 PMTs → 8'280 PDMs)
  - 5x5 cm^2 SiPM array + electronics
- mother board
  - 25x25 cm^2 PDM array + steering module + optical transmitters







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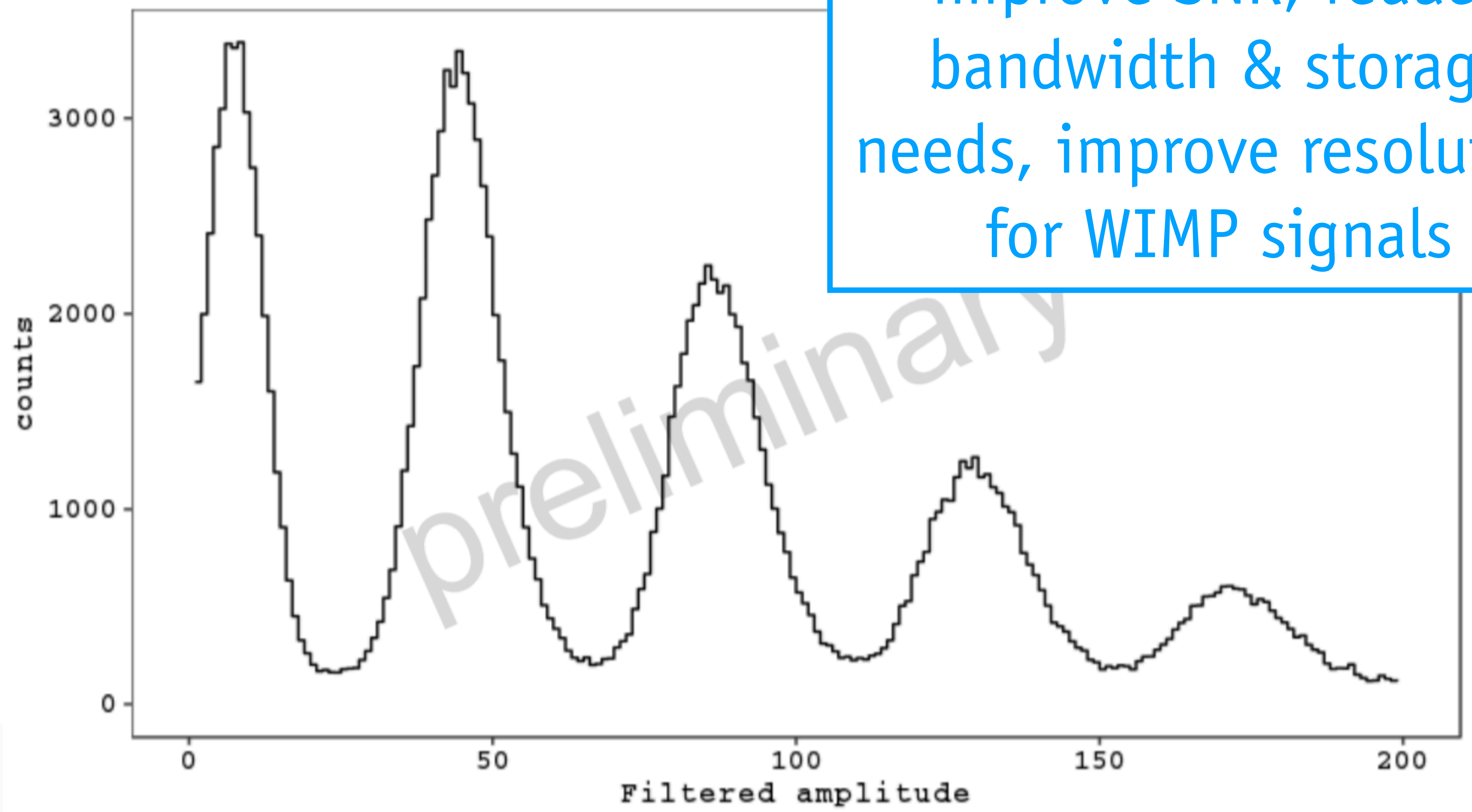
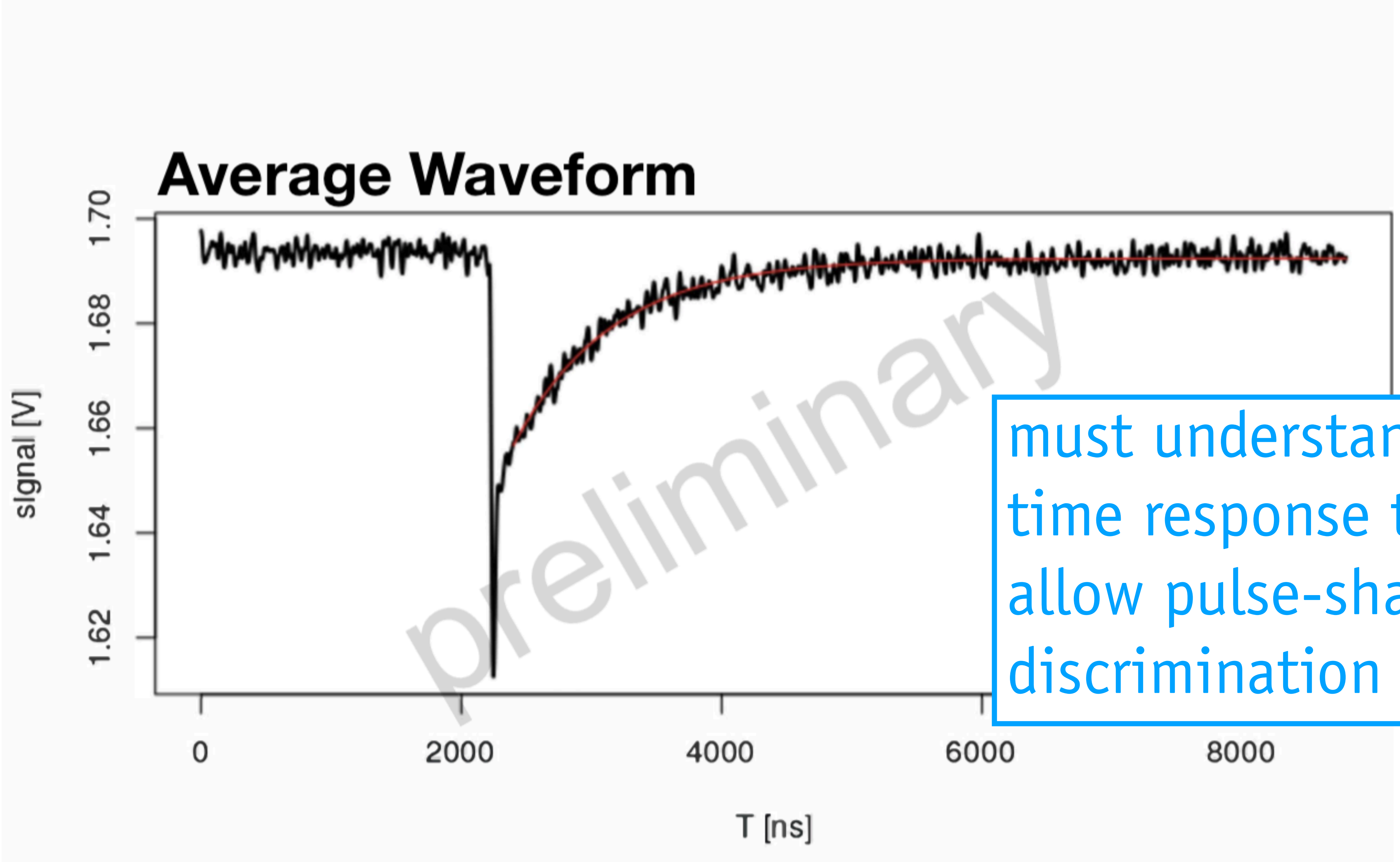
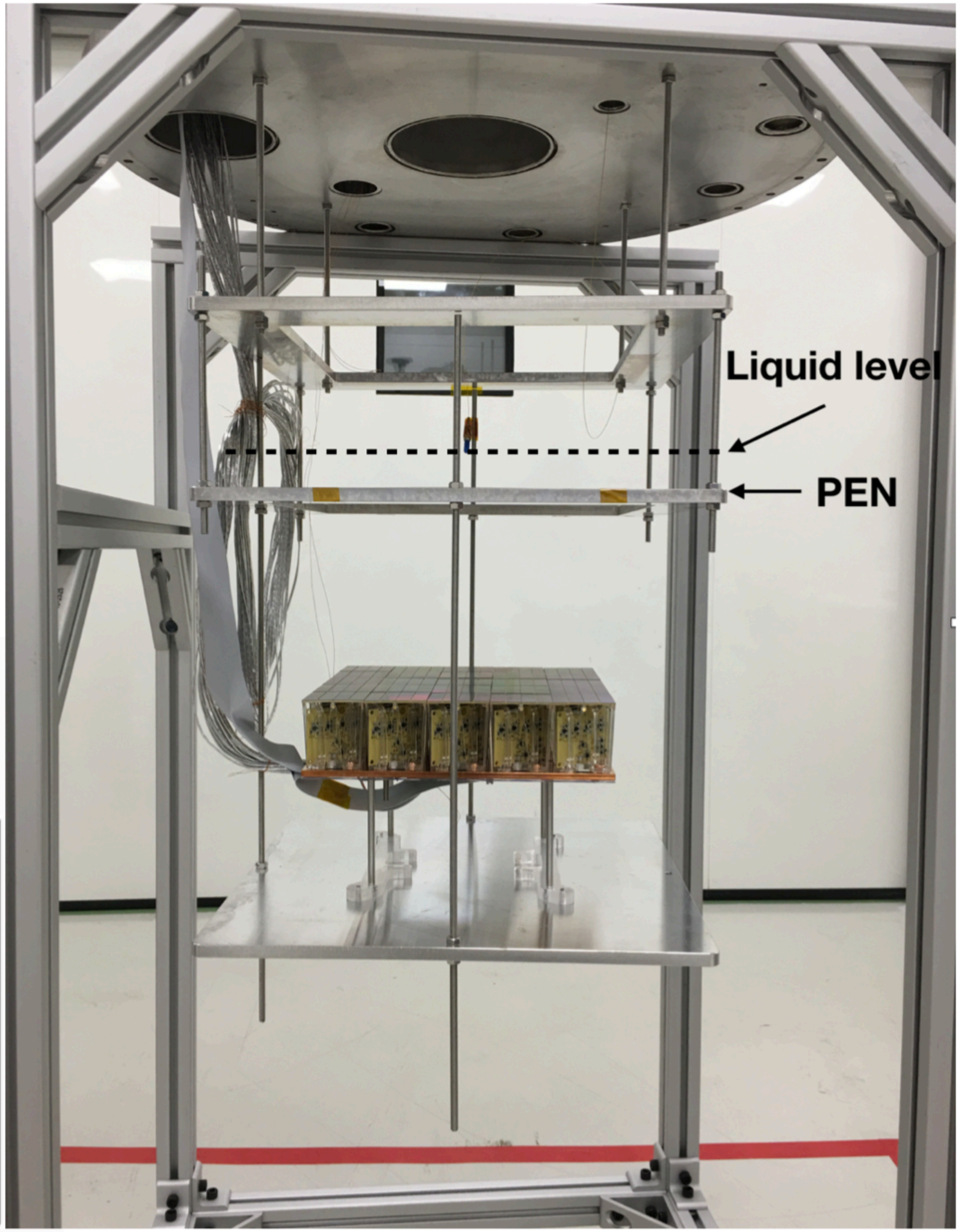


use digital filter to improve SNR, reduce bandwidth & storage needs, improve resolution for WIMP signals



must understand time response to allow pulse-shape discrimination



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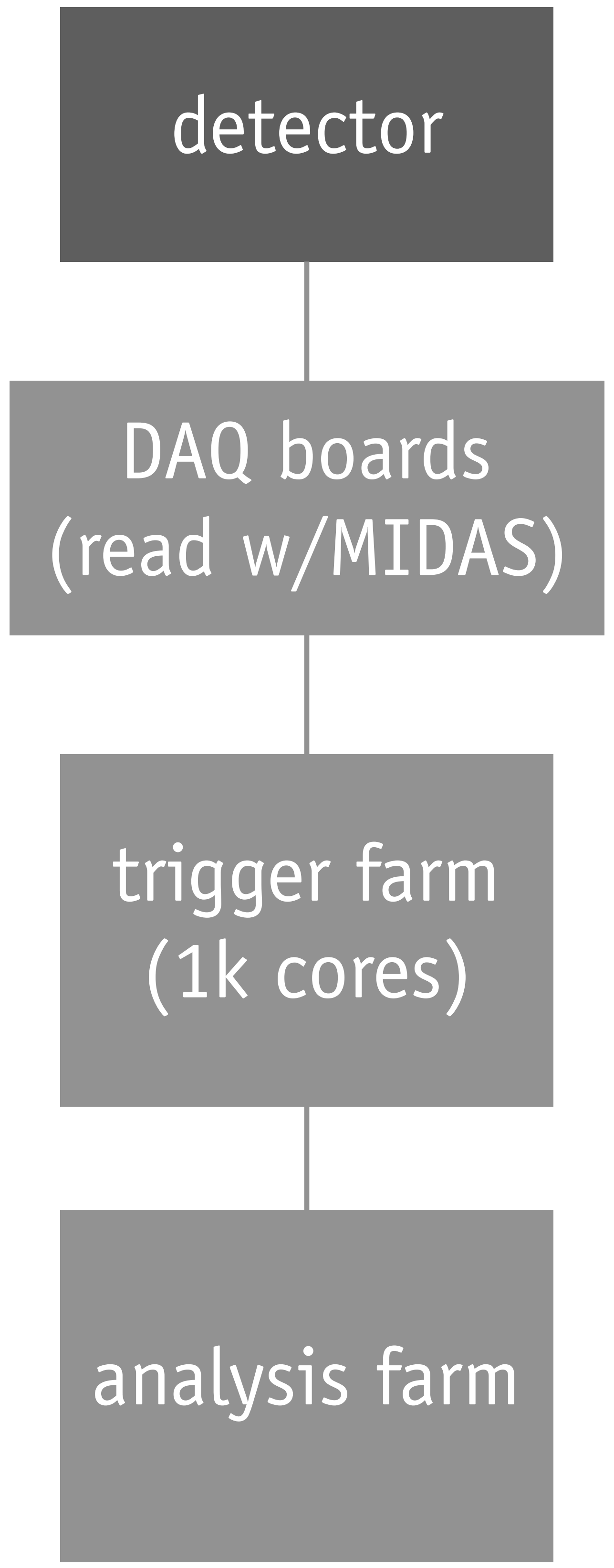
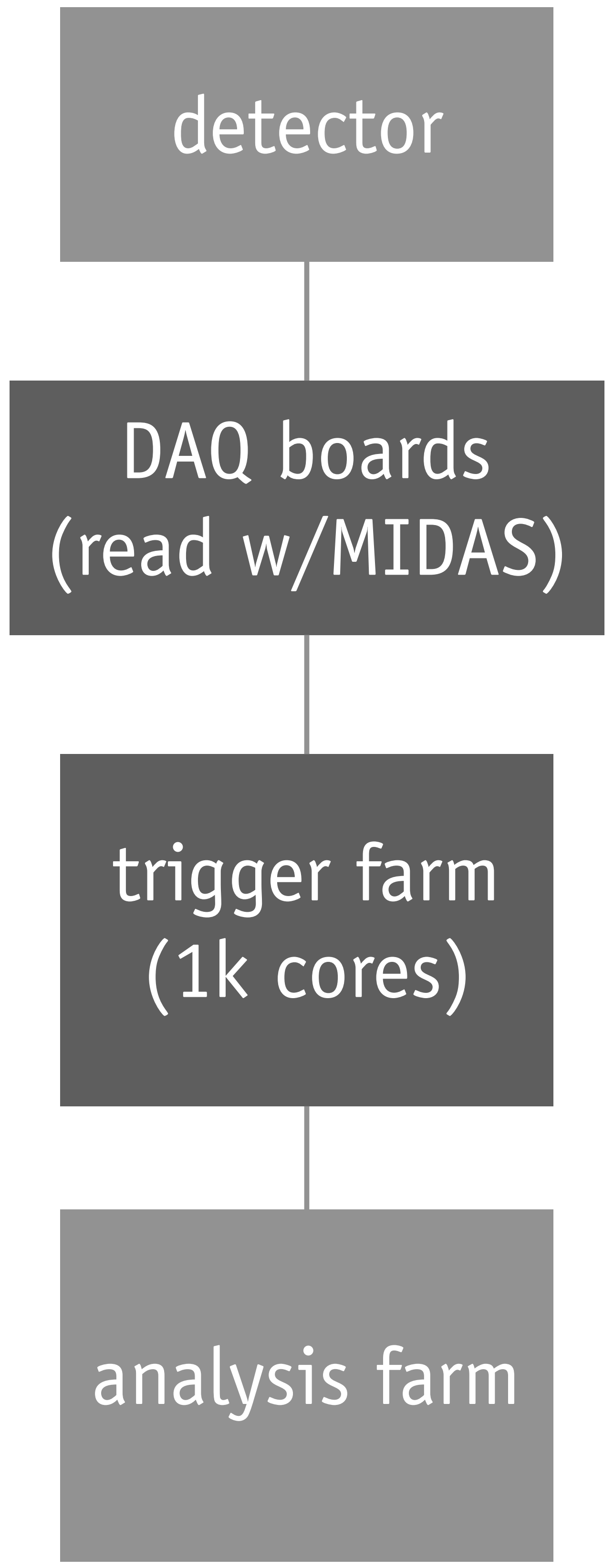
A TDAQ AS CHALLENGING AS LHC EXPERIMENTS?

- **TPC signal means 10k PDM channels**
  plus ~3k for the veto
- **dominated by dark rate ~200 Hz/channel**
  ~50 Hz from ^{39}Ar, 100-200 Hz total from background
- **3.5 m drift @ 200 V/cm, a.k.a. 4 ms**
  10 p.e./keV in TPC, ~1 p.e./keV in veto
- **waveform length to be saved depends on S1 and S2**
  ~7 µs for S1, ~20 µs for S1; veto: coincidence within ~2 ms



[#1] TRIGGER, OR: DECIDING WHICH EVENTS TO SAVE

- **strategy: reduce data with multi-level firmware+software trigger**
  plus hardware-level single-photon discrimination & downsampling
- **working on implementation on flash ADC digitizer boards**
  CAEN 64-channel 14-bit 125 MS/s with Xilinx Zynq Ultrascale+ FPGA
- **what goes on boards and what goes on CPU depends on performance**
  work ongoing on fast (e.g. ARMA-based) filter implementation
- **output will be hits (time and number of photons)**
  or full, downsampled waveform for specific S2 signatures or veto PDMs



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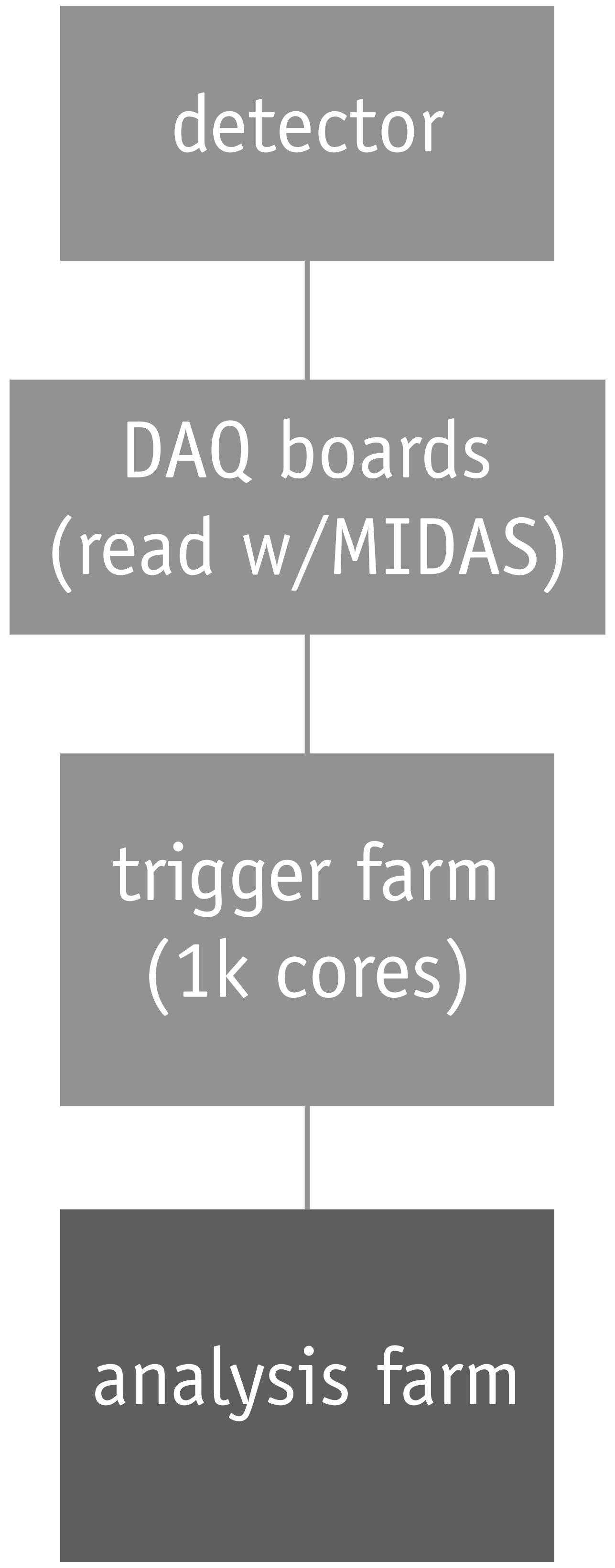
[#2] RECONSTRUCTION

- **reconstruction based on output of SiPM filtering ("hits")**
  pulse-shape discrimination, clustering and machine learning (e.g. position reco)
- **current implementation in python**
  numpy-based, cython for tailored optimisation
- **software framework being built up with prototype detectors**
  including integration with calibration database and slow-control
- **raw data in MIDAS format, analysis output in ROOT**
  reconstruction interfaced also to Geant4-based Monte Carlo simulation with G4DS



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[#3] DATA STORAGE AND ANALYSIS

- **target event size of a fraction of MB (may increase optimising efficiency/physics reach!)**
  dominated by duration of the saved waveform from the veto (0.5-2 ms)
- **software trigger needed to reduce the ~5 GB/s of total TPC rate**
  assuming 200 Hz of trigger rate and a target of ~100 MB/s
- **total data on disk ~1 PB/year for 10 years**
  with combination of hardware and software trigger and fast processing
- **(data and MC) processing based on LCG-like computing model**
  virtual organisation, disk and tape replicas at European and North-American tiers

CHALLENGES

- **could reach neutrino floor using DS-20k technologies**

  ton-scale detector with ultra-pure argon and SiPMs

- **multi-level trigger strategy necessary to reduce data rate**

  ~10k channels, few m drift

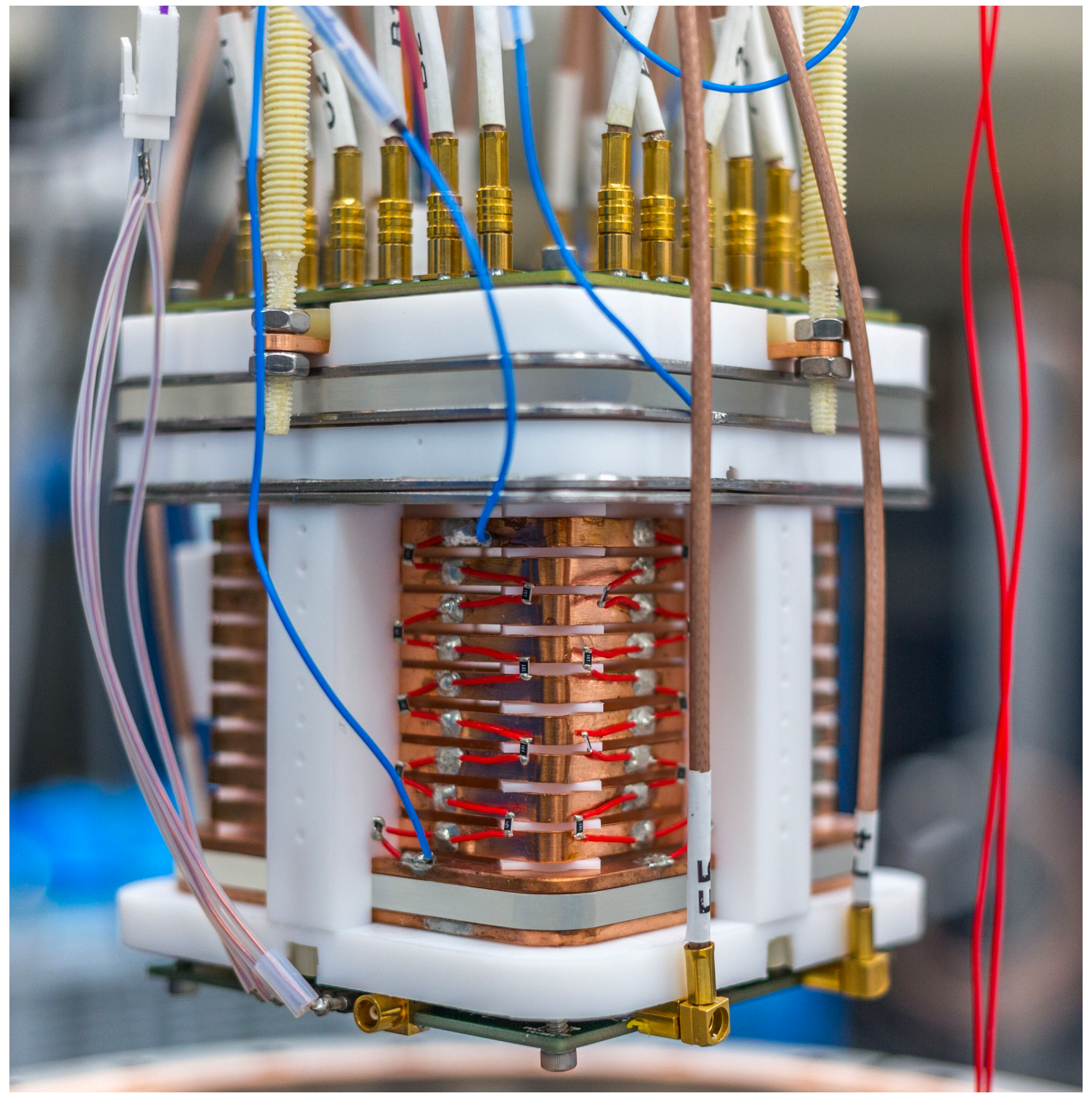
- **LHC-like computing system**

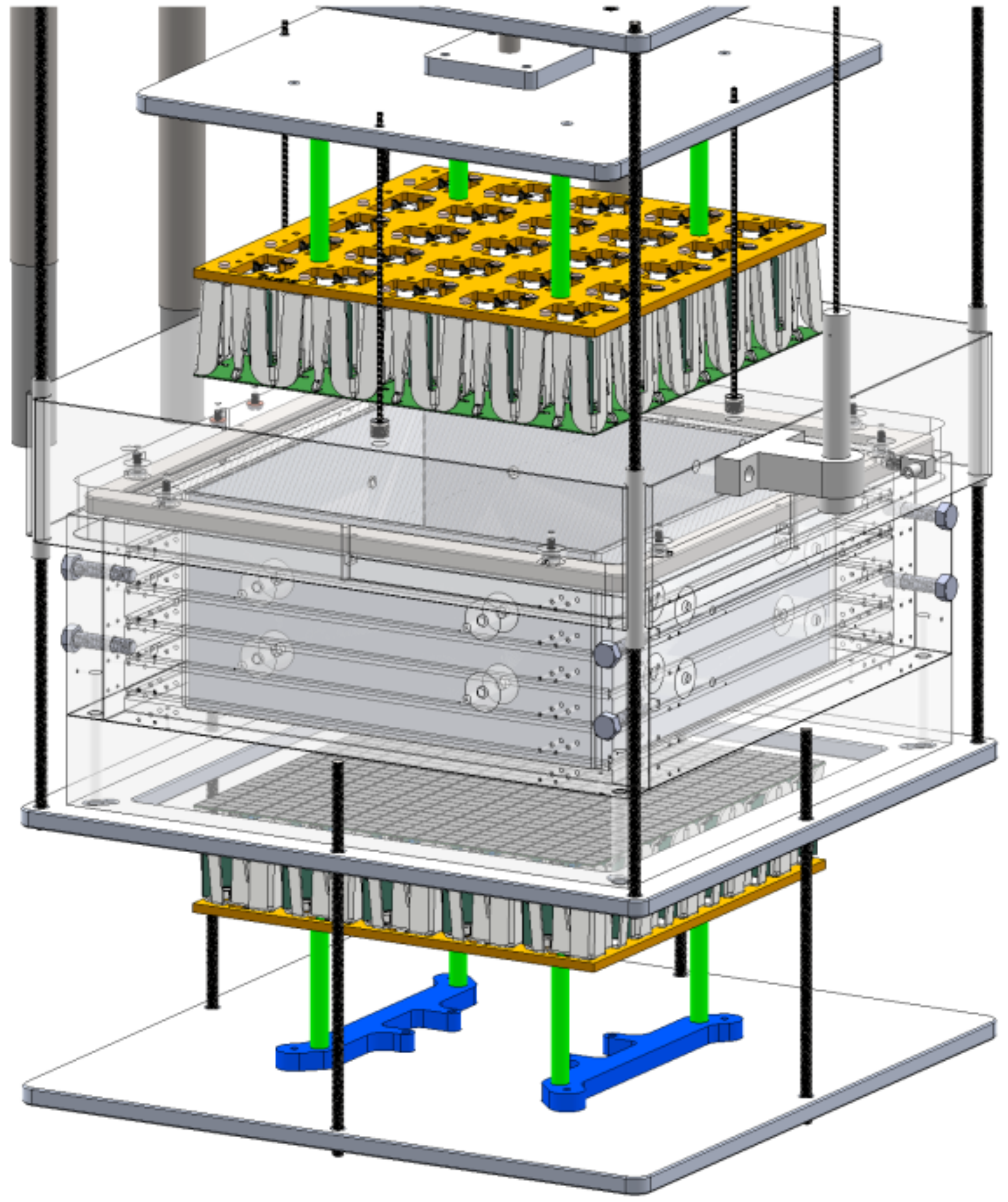
  re-use LHC experience when possible (e.g. VO, CVMFS, RUCIO, DIRAC...)

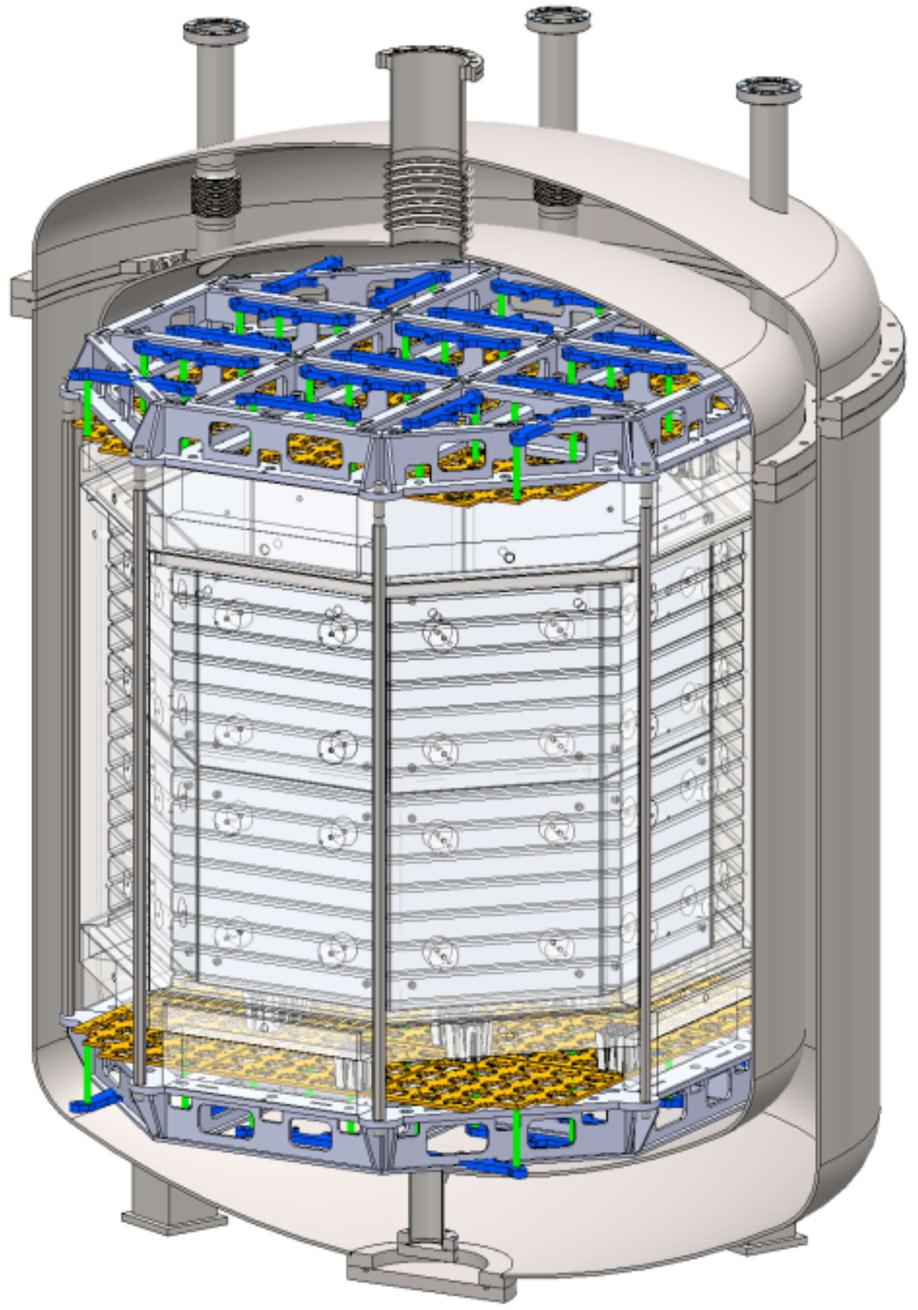
- **need clever reconstruction algorithms**

  ideal test bench for fast signal processing and machine learning

Scalable







- ReD
  - $5x5x5\ cm^3$ TPC with 2 PDMs
  - directionality
- Proto-0
  - commission first motherboards and TDAQ @ CERN
- Proto-1
  - commission 370 PDMs
  - study final configuration

A Global Argon Dark Matter Community

2019
ReD
Proto-0
Seruci-0

2020
Proto-1
Seruci-1

2022
URANIA (60 t)
NOA

2022
Darkside-20k
(commissioning)

2025
Seruci-2?
(towards ARGO)

2028
ARGO
(neutrino floor)

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Backup

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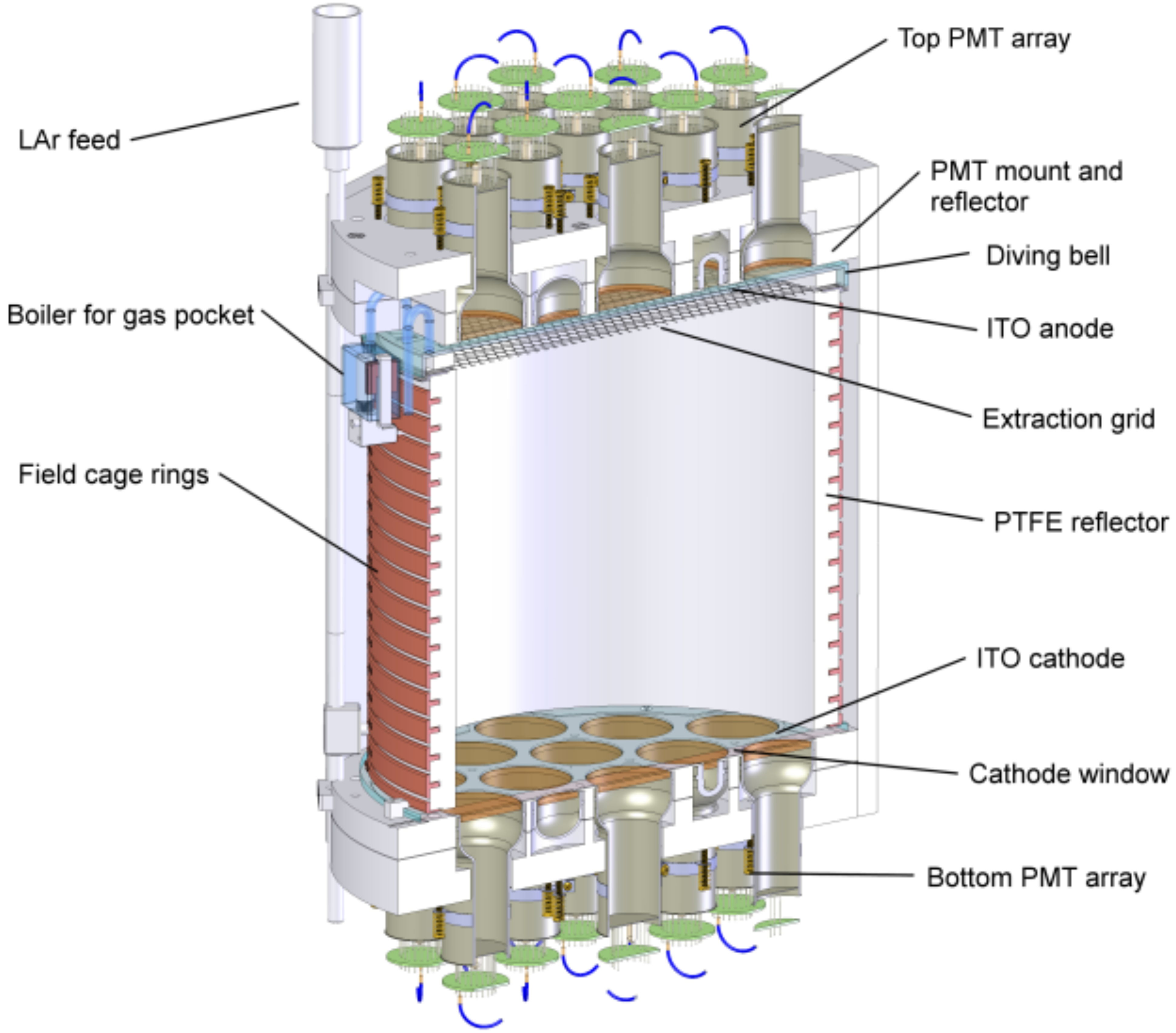

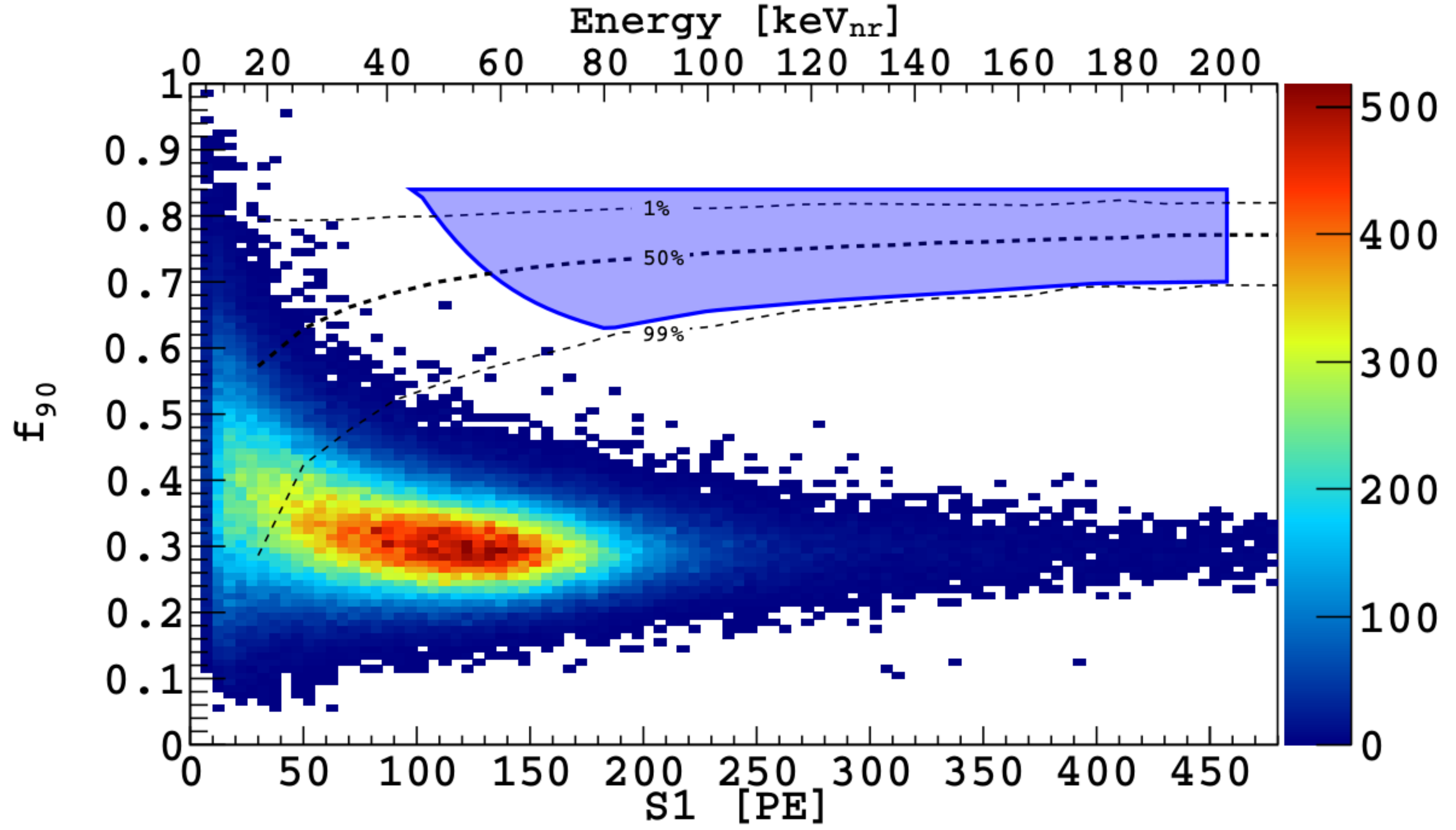

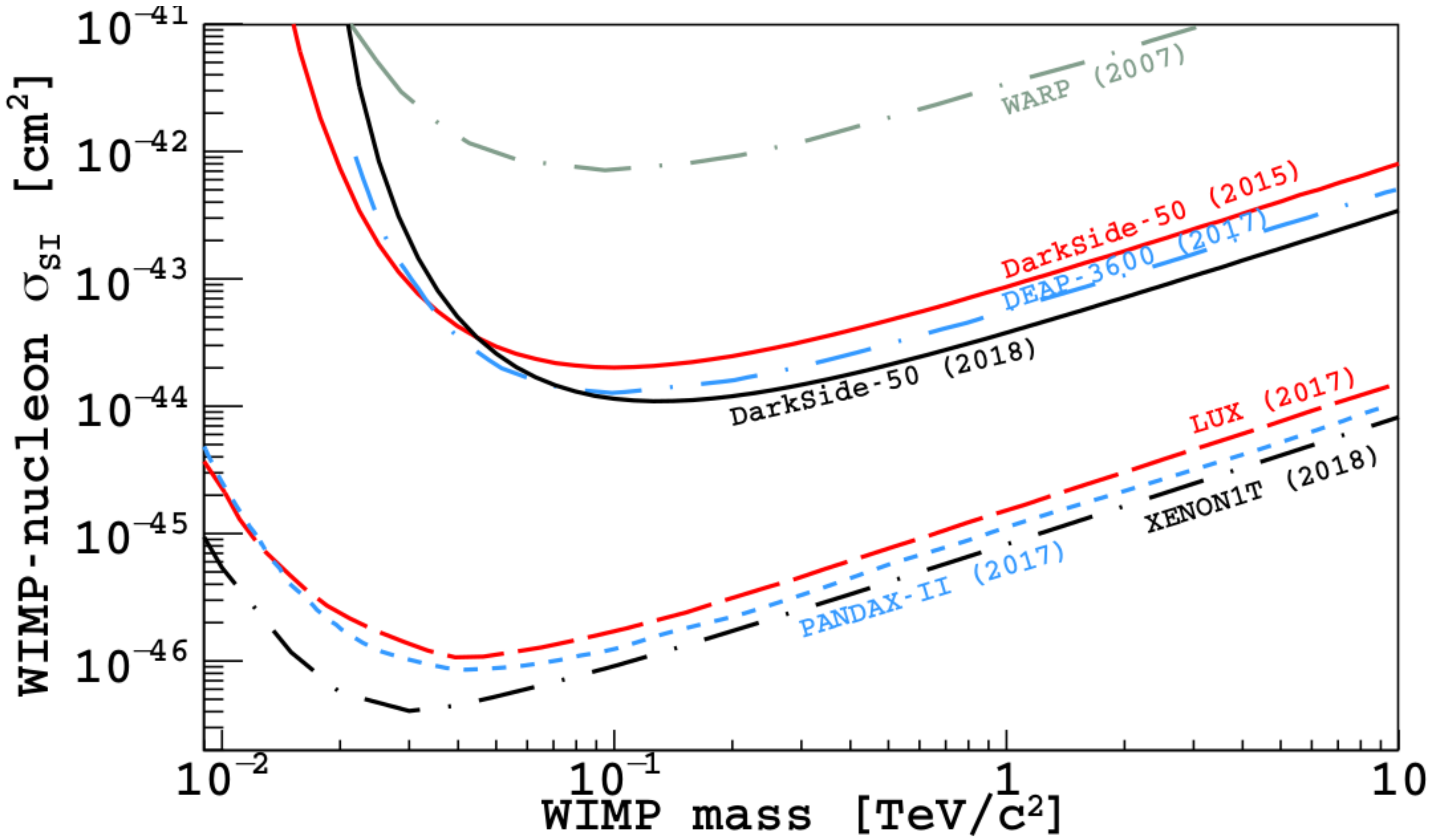

Darkside-50

- 530 live days x 46 kg
- 1.14×10^{-44} cm^2 @100GeV
- underground Ar ~ 0.7 mBq/kg
- LY ~ 8 photoelectrons/keV

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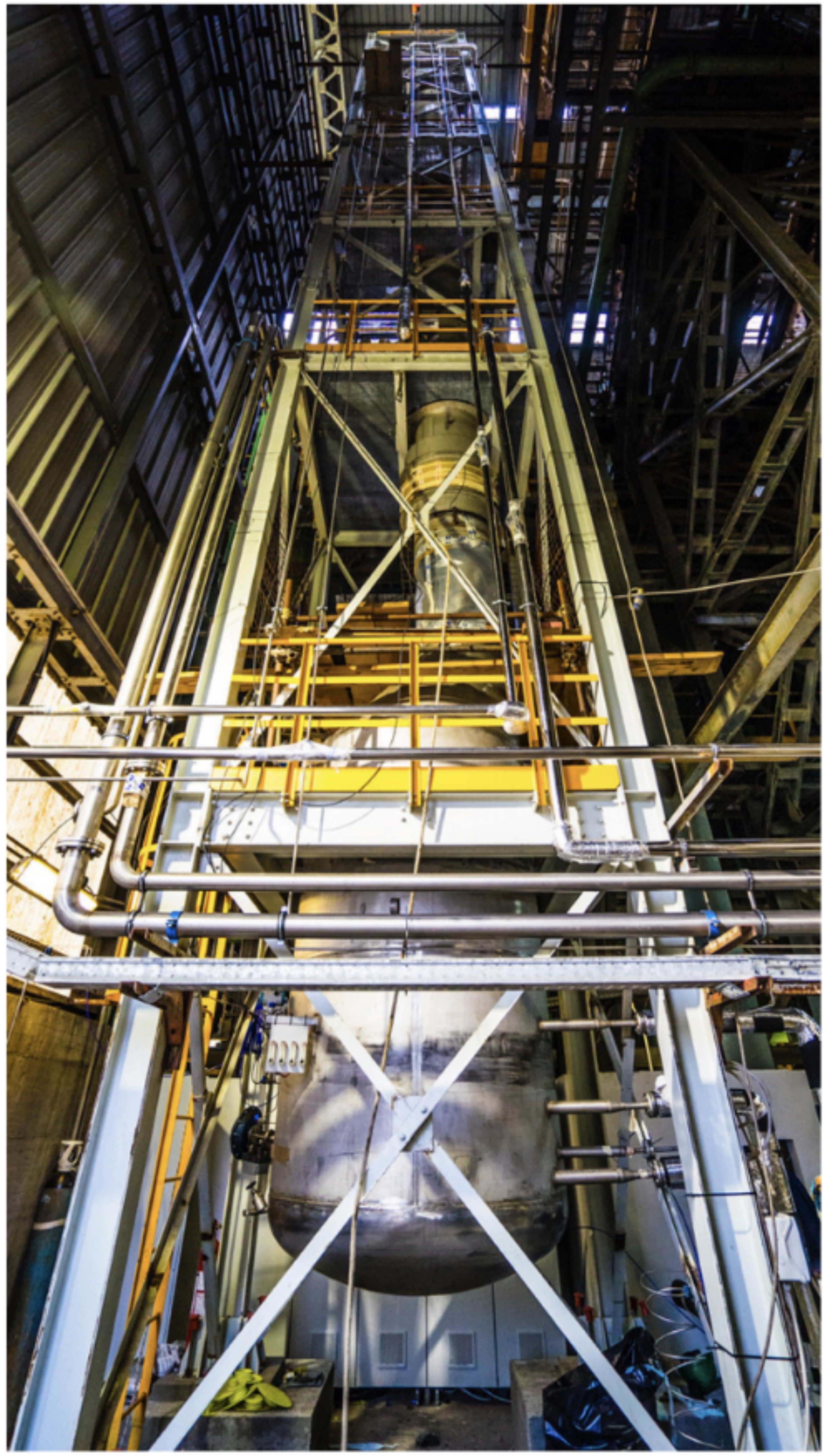
bigger or **better**?

Pure

- underground Ar
  - from CO_2 wells in Colorado (URANIA)
  - 250 kg/day, 60 t total
- purification
  - in Sardinia (ARIA)
  - 350 m distillation column
  - 1 t/day



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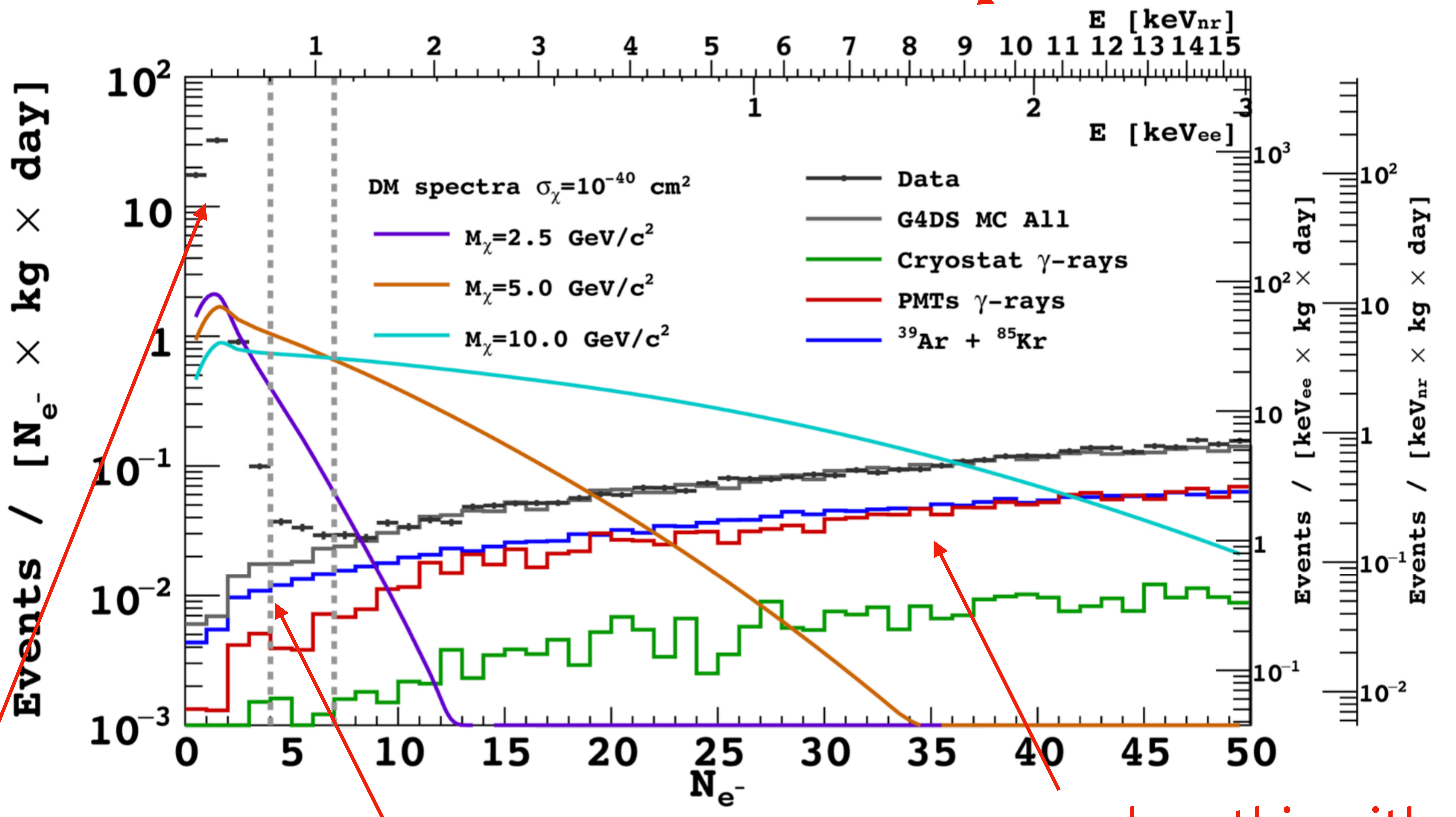
- look only for ionisation signal (S2)
  - reach lower recoil energy (~2 keV_{nr})
- can study seasonal modulation
- experimentally challenging

calibrate this energy scale



characterise this background

reduce this with URANIA (^{85}Kr) + ARIA (^{39}Ar)

reduce this with radio-pure SiPMs

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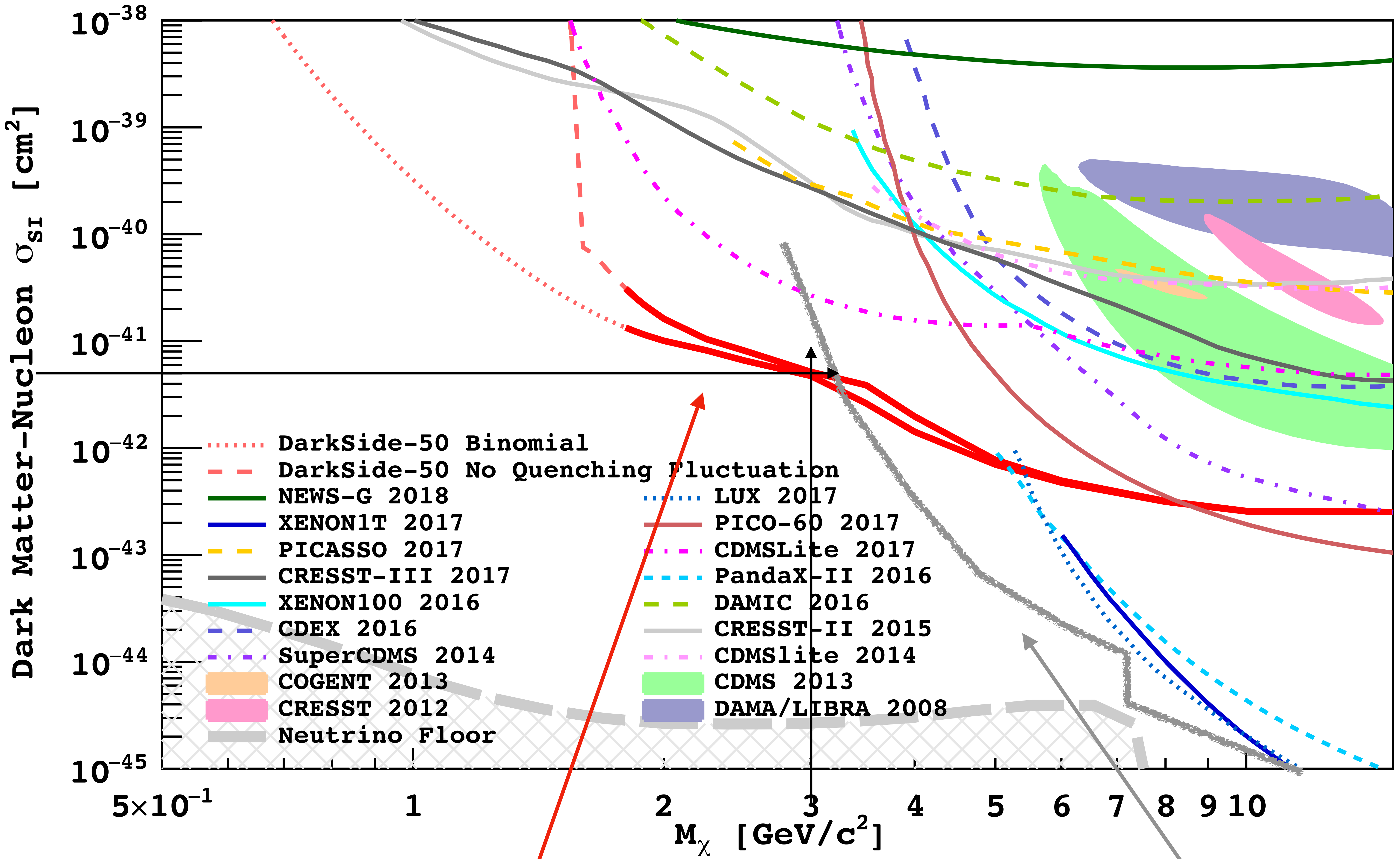

50 kg of Ar [6.7 ton days]

1 ton of Xe [22.3 ton days]

arXiv:1907.11485

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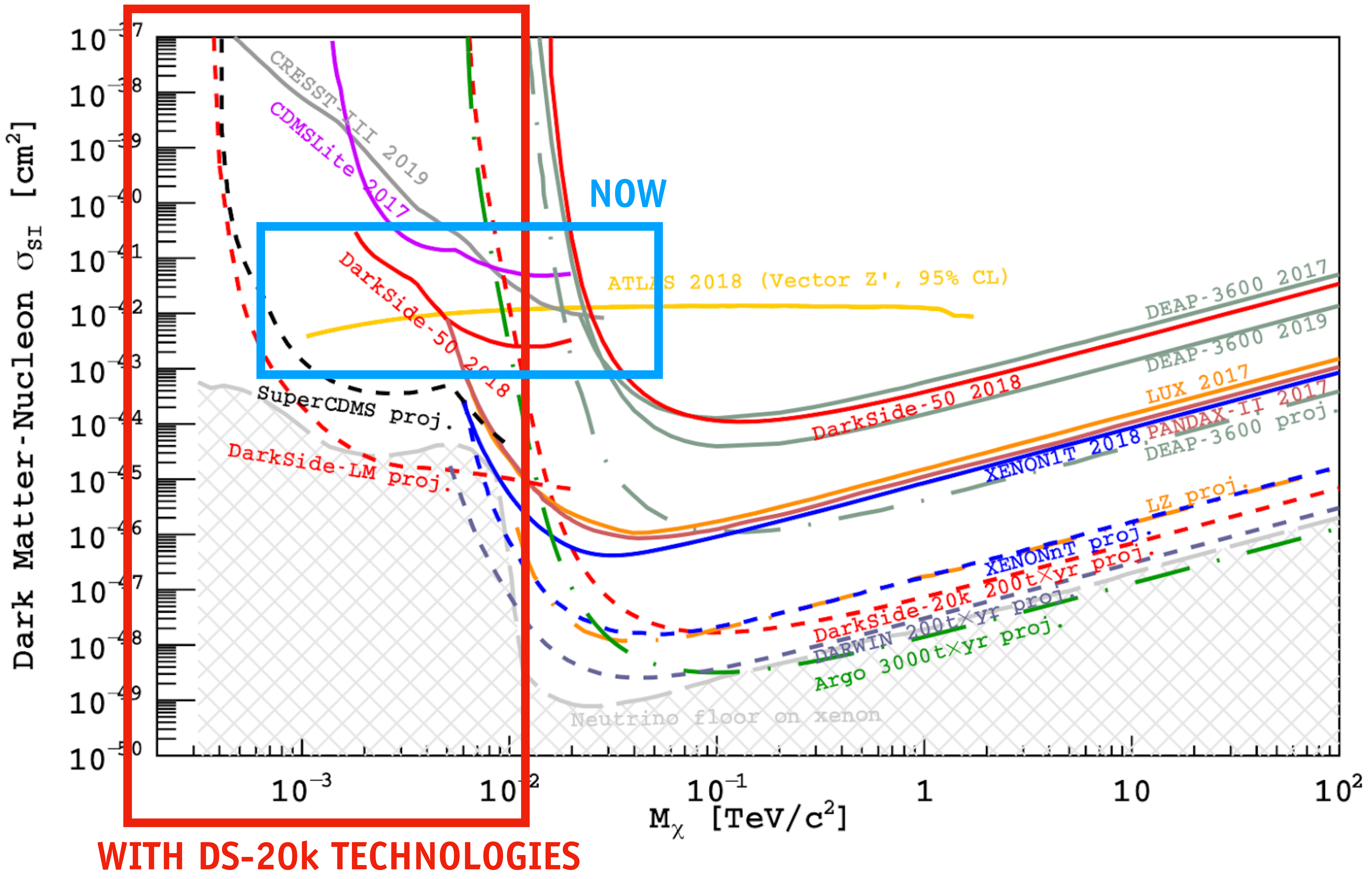

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Entries
1200
1000
800
600
400
200
0
0
50
100
150
200
250
300
Amplitude [Arb.Units]
Gain: 52.68
σ_b: 2.19
SNR: 24.1
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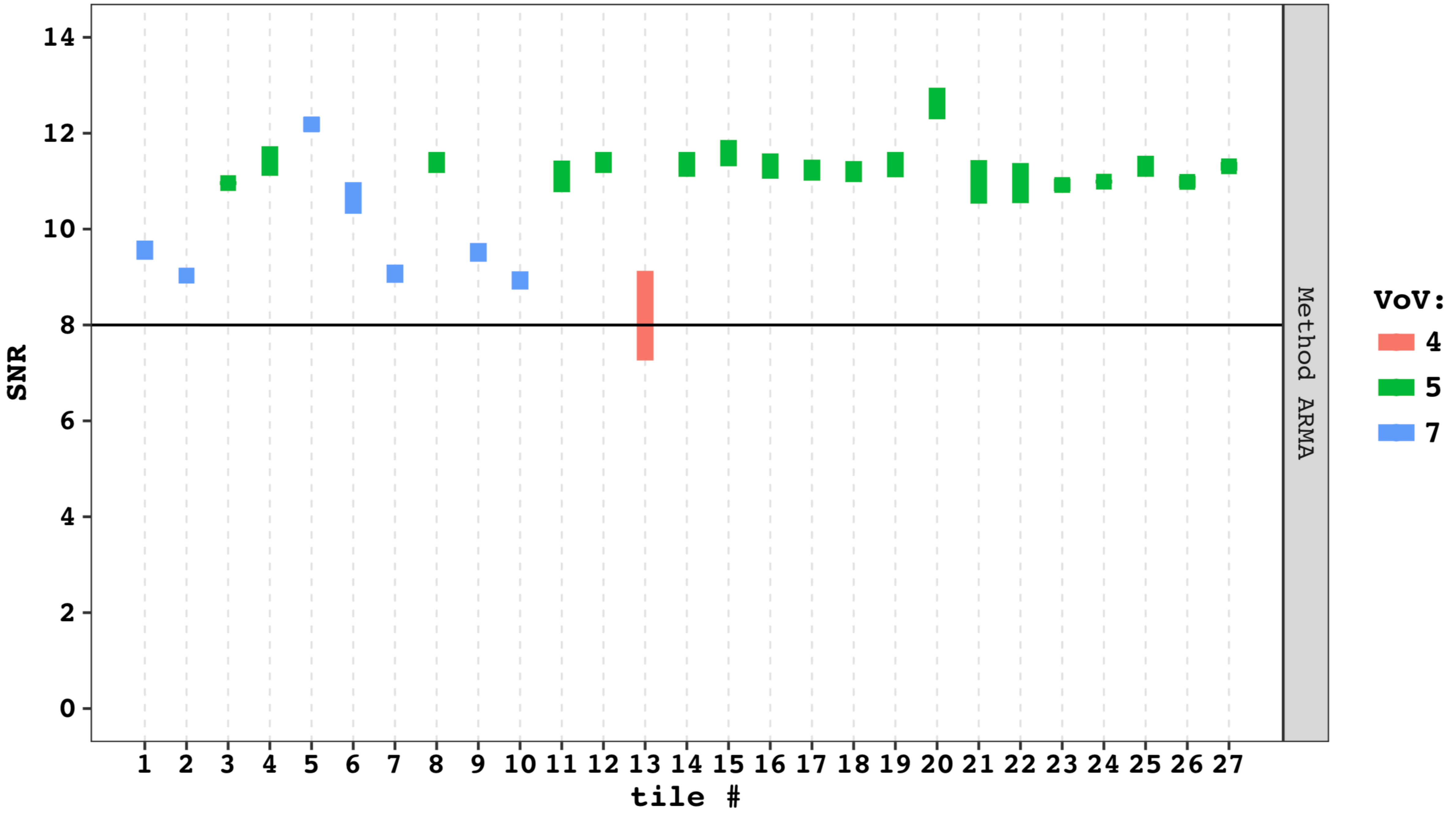

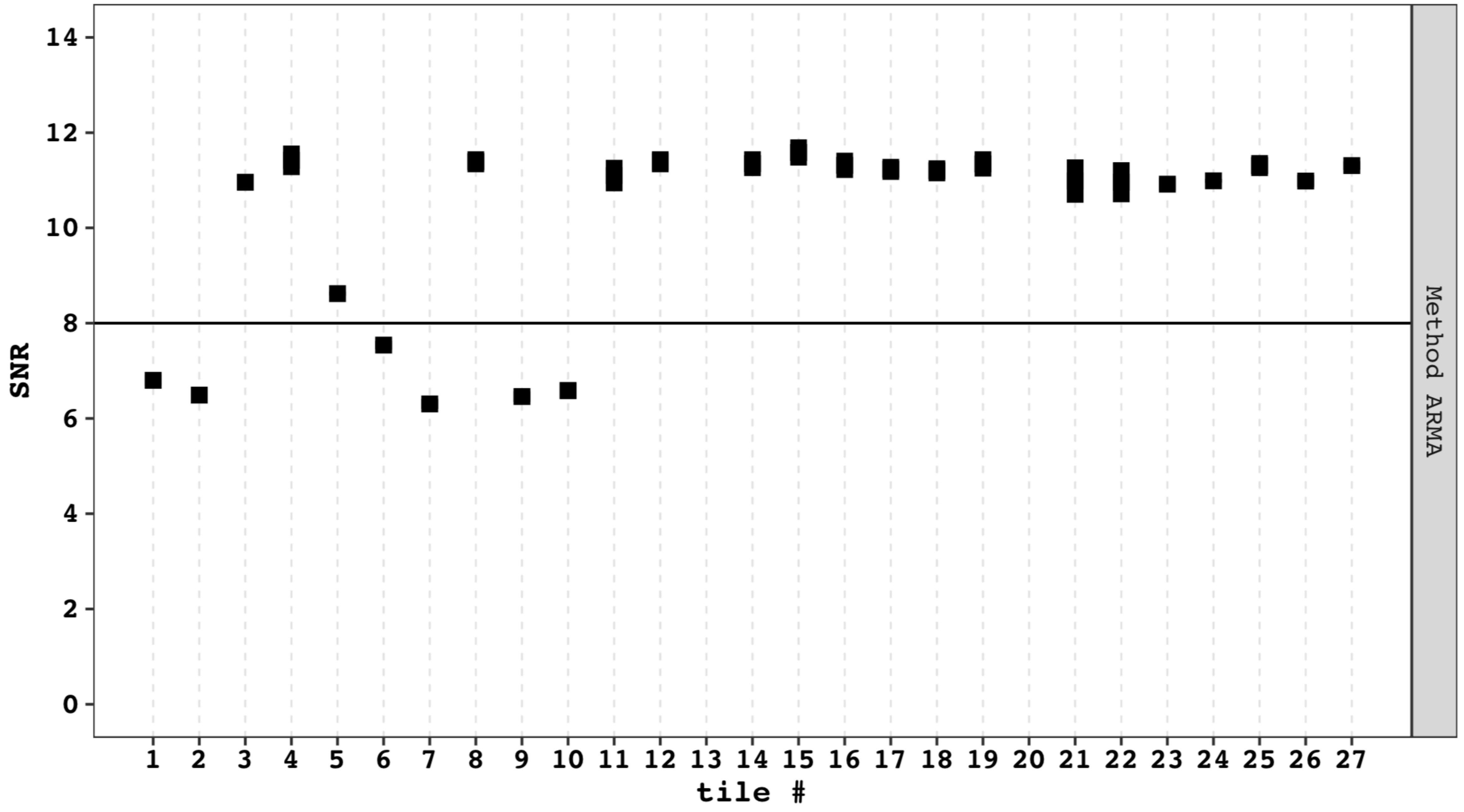

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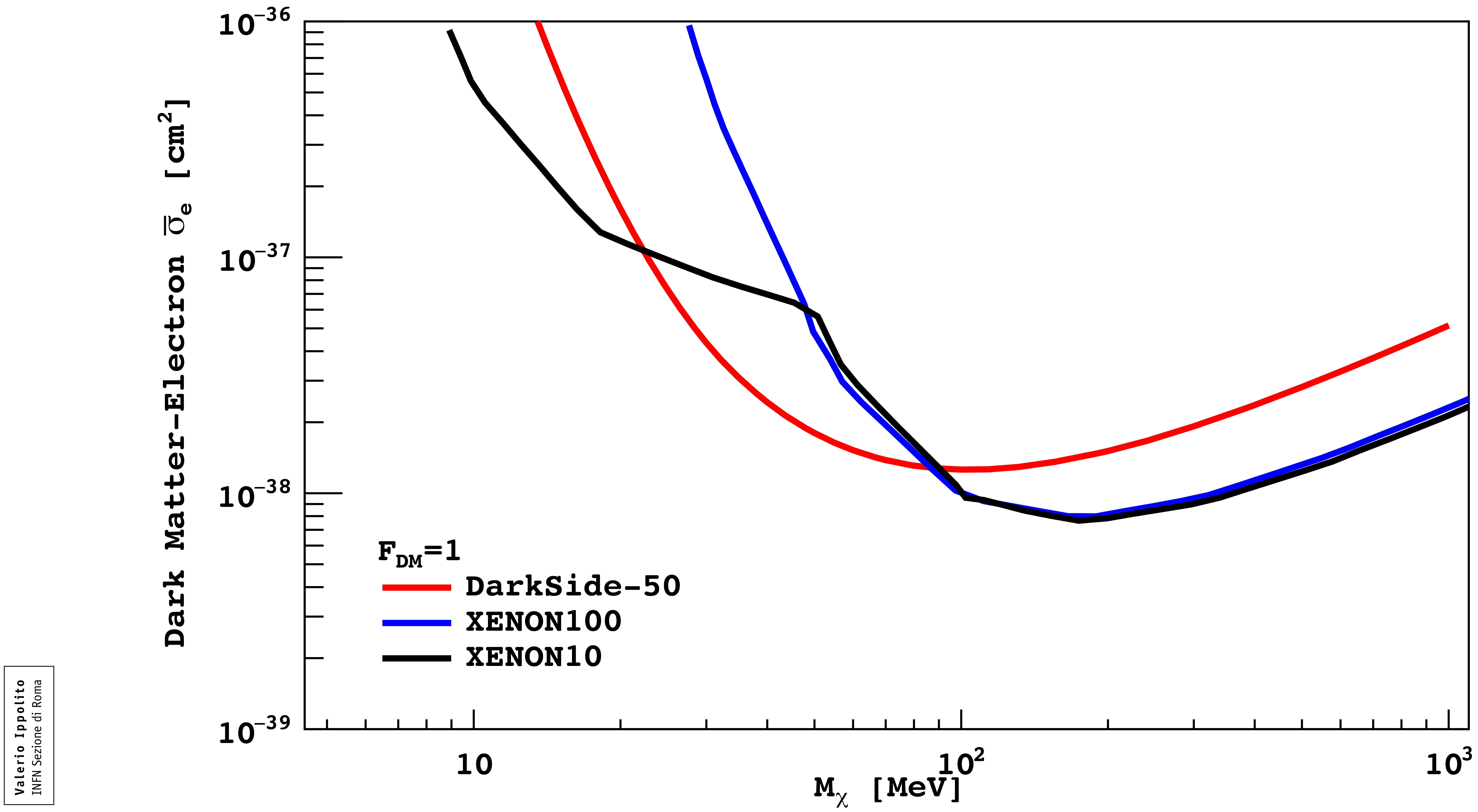

Dark Matter-Electron $\overline{\sigma}_e$ [cm^2]
10^{-36}
10^{-37}
10^{-38}
10^{-39}
10
10^2
10^3
M_χ [MeV]
F_{DM}=1
DarkSide-50
XENON100
XENON10
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